Sustainable electric energy supply by decentralized alternative energy technologies

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Abstract
Energy is a fundamental component of human life with strong link to the living standard. It is important to understand that this important human life component is used in a sustainable way. Sustainable energy from production, consumption, and environmental point of view is research fields of many researchers around the world. The real question is how energy can be used in a sustainable way and how decentralized alternative sources can contribute to sustainability of energy.

Currently, fossil fuel, world-wide, and nuclear energy, in some countries are the main source of energy in both developed and developing nations. Using these sources, which extract fuels from finite earth resources, is associated with some environmental and social problems. We may have to make some major changes if we wish to address the challenges of sustainable energy. Many pressures are focused on electrical energy, in terms of its supply technologies and efficiencies. These concerns have often been expressed in demands for less use, greater end-use efficiencies, and more reliance on alternative sources such as solar photovoltaic (PV) energy, wind power and other sustainable power supplies.

The objective of this paper is to discuss some of the issues related to current energy structure from sustainability point of view and highlight the opportunities provided by decentralized renewable energy-based distributed generation technologies, for meeting the challenges of a sustainable power supply. A further objective is to present a sustainable energy model as well as the results of a computer simulation program developed for this purpose.

1. Introduction

The most available and affordable sources of energy in today's economic structure are fossil fuels, namely, oil, gas, and coal [1]. Fossil fuels are non-renewable; they have limited reserves, with serious environmental problem associated with their use. The majority of energy produced by these sources are polluting, and damaging to ecosystems. Coal and nuclear energy are used in central and bulky power station to produce electricity, and then this electricity is delivered to customers via expensive transmission lines and distribution systems [2], [3]. Transmission and distribution lines are important components of current power grid structure. Delivering electric power via transmission and distribution lines to the electricity users is associated with high electric power losses. These power losses are costly burdens on power suppliers and users. One of the advantages of decentralized generation (DG) is to that DG is capable to minimise the power losses in the line because electric power by DG is generated at the demand site.

2. World's limited energy reserves

Oil and gas are currently used at record level. These two are limited in terms of their reserves. Nobody knows how much oil and gas still exists under the earth's surface. And also nobody knows how many years it will be possible to produce oil in the future. All numbers we have at best, informed estimates.

- ***Oil***

According to Oil & Gas Journal [4], the world's proven reserve of oil amounted to 1318 billion barrels (2006). Similar Figures have been published by other sources e.g. 1140 billion barrels (OPEC) [5], 1226 billion barrels (IEA) at current production rate of 84 million barrels per day [4]. Oil reserves are concentrated mainly in OPEC countries (Organization of Petroleum Exporting Countries), especially in those OPEC members of the Middle East. According to IEA, more than 75% of oil reserve is in the OPEC countries. According to the same source, almost 65% of oil is in the Middle East region. Figure 1 shows world's oil distribution in giga tonnes coal equivalent (gtce).
(1 gtce=29.3076 x 10^{18} Joules). Figure 2 shows world oil in billion barrels.

- ***Gas***

Worldwide proven gas reserves have increased by more than 80% over that past twenty years and it is expected more gas resources being recovered in the Middle East, Russia, and Central Asia. Almost 40% of gas is in the Middle East region [1], [4]. Current 180 trillion cubic meter world gas resources are more than sufficient to meet current demand for more than 50 years, even with projected demand increase. Gas contribution to the world energy mixed has increase from 16% in 1973 to 21% in 2005. According to IEA's Reference Scenario, gas demand will grow at rate of 2% per year by 2030, from 2.8 trillion cubic meters in 2005 to 3.6 trillion cubic meters in 2015 and to 4.7 trillion cubic meters in 2030, (Trillion = 10^{12}). The biggest increase occurs in developing countries, China & India. Gas supply infrastructure to meet this production increase is predicted to need an investment of $3.9 trillion by 2030 [1]. Figure 3 shows world's distribution of gas.

3. Coal, an environmentally unsustainable option for electricity generation

Coal is plentifully available everywhere including Australia. But energy source is considered as polluting option for electricity generation. Research suggests that the public is not fully aware of the significant role of coal fired power in the greenhouse pollution problem. Opinion polls and focus groups reveal that most people do not realise the central role of coal in the production of the electricity, nor its major role in causing global warming.

More than 50% of coal reserves are located in just 4 countries i.e. the USA, Russia, China & Australia. Coal is mainly used for electric power generation [2]. In 2004 for example 6945 TWh of the world electricity, (almost 40% of the world electricity 17450 TWh) was produced in coal-fired power stations. This number was 2340 TWh in 1973 with the similar percentage. According to IEA's Reference Scenario global coal demand will grow at rate of 1.8% per by 2030. Share of coal in global energy mix remains broadly constant at 25%. Proven reserve at the end of 2005: 909 billion tones, equivalent to 164 years of production at current rate. World-wide, fossil fuels will remain the dominant source of energy by 2030. However, from environment point of view, coal is not a sustainable source of energy. Figure 4 shows world's distribution of coal.

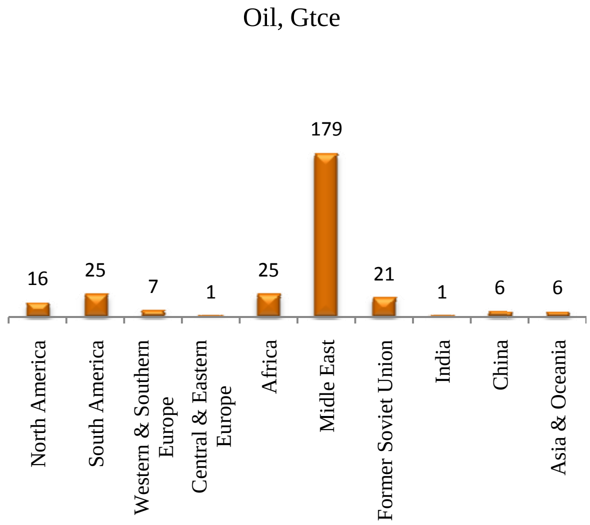

Figure 1 world's oil distribution

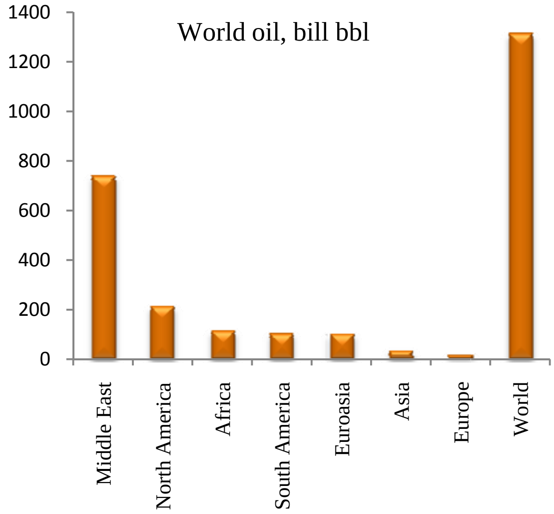

Figure 2 world's oil distribution in bill bbl

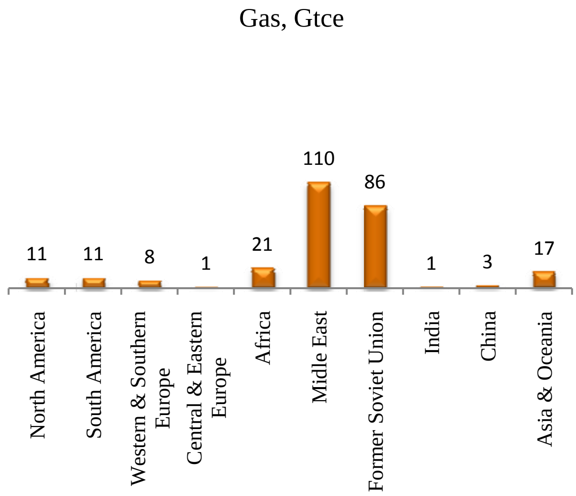

Figure 3 world's gas distribution

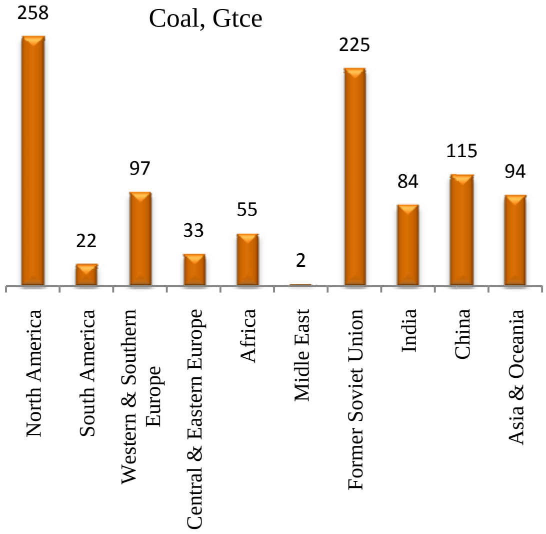

Figure 4 world's coal distribution

4. Nuclear option

Nuclear power, a proven technology for base-load electricity generation, could make a significant contribution to reducing GHG emissions. Use of nuclear energy for electricity generation has always been associated with some social and security issues. It is predicted that nuclear energy capacity will increase to 416 GW by 2030 from 368 GW in 2005. However, nuclear share in total world electricity generation drops from 16% to 10% [1], [2].

Nuclear power is very capital intensive ($2 - $3.5 bill/Reactor). Economy is not the only factor determining construction of new nuclear power plant [1], [2]. Safeties, nuclear waste disposal, the risk of proliferation are real challenges which have to be solved to the satisfaction of the public before construction of a nuclear power plant starts. This technology is also very energy intensive. This means that almost 10% of the energy that a 1000 MW nuclear power plant can produced during its life time of 30 years is used to make it. Unlike oil & gas uranium resources are widely distributed around the world. Nuclear power plants produce electricity at relatively stable cost, because the cost of fuel represents only about 15% of the production cost. In gas-fired power plant, cost of fuel is about 75% of the production cost.

Nuclear electricity is water intensive. At the time of increasing water scarcity, nuclear energy cannot offer a reasonable and sustainable solution. For every kilo watt of electricity that is produced in a nuclear power plant, almost 2.3 litre of water is consumed [7].

According to CSIRO [8], there are 1962 kilo tones of uranium worldwide available (proven resource), 716 kilo tones (36.5%) of this amount is in Australia. With the current level of uranium production (8 – 10 kilo tones of enriched uranium is needed every year), experts believe that the uranium reserves will be finished in about four decades, so from sustainability point of view it is not a sustainable resource.

5. Cleaner and sustainable options

The growing awareness of the impacts of greenhouse gas emissions on global climate change has necessitated a reassessment of the current approach to achieve a sustainable energy for the future. Without any doubt, the increasing utilization of alternative sources is the key to a cleaner and sustainable energy in the future. Cleaner options are:

- **Hydro**

According to the World Energy Council more than 45000 hydro power plants operational with a generating capacity of 800 gigawatts and they currently supply almost one-fifth of the electricity consumed worldwide [14].

- **Biomass**

Wood, crop residues and other biological sources are an important energy source for more than two billion people. Mostly, this fuel is burned in fires and cooking stoves, but over recent years biomass has become a source of fossil-fuel-free electricity.

- **Geothermal**

Earth's interior contains vast amounts of heat. Because rock conducts heat poorly, the rate at which this heat flows to the surface is very slow. The slow flow of Earth's heat makes it a hard resource to use for electricity generation except in a few specific places, such as those with abundant hot springs. Italy, New Zealand, the USA are among small number of countries produce geothermal electricity.

- **Ocean energy**

The oceans offer two kinds of available kinetic energy the tides and that of the waves. Neither currently makes a significant contribution to world electricity generation, but this has not stopped enthusiasts from developing schemes to make use of them.

- **Solar and Wind**

The last two sources (solar & wind) are considered as success story of the last 2 decades [6]. However, the intermittency nature is considered as weakness of these sources.

- **Why solar energy is important?**

Solar energy is sustainable and widely available almost everywhere. Solar energy technologies use only ordinary materials. Solar energy uses a resource that is far larger than required to provide all of the world's energy [11]. A simple calculation shows that the amount of energy received in one hour by the earth from the sun is equivalent to world energy consumption in one year. Unlike nuclear, solar energy has no security and military risk. Unlike oil & gas, solar energy is available almost everywhere. Unlike fossil fuels, solar energy has minimal environmental impacts. No increases in the cost of fuel, routine maintenance is far less than conventional plants, and the fuel (sun energy) does not have to be transported. Australia with the world's highest sun radiation has the potential to lead the world in relation to using solar energy for electricity production [9].

- **Why wind power is important?**

Wind turbines use freely available wind to generate electricity, wind energy conversion is mature technology, in some cases the energy production cost ($/kWh) as low as conventional power generation technologies. Environmental Issues are very low; wind energy contributes to security of supply, and together with storage able to serve the base load. Both sun energy and wind power are considered as fast growing technologies of the past two decades. Figure 5 shows the development of the world solar photovoltaic capacity [2], while Figure 6 shows development of the world wind power capacity [10].

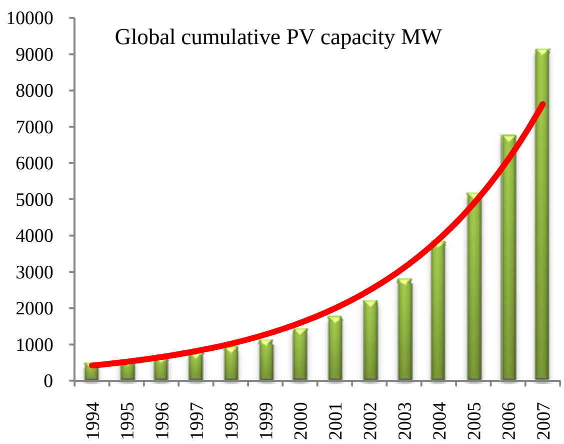

Figure 5 global PV energy capacity

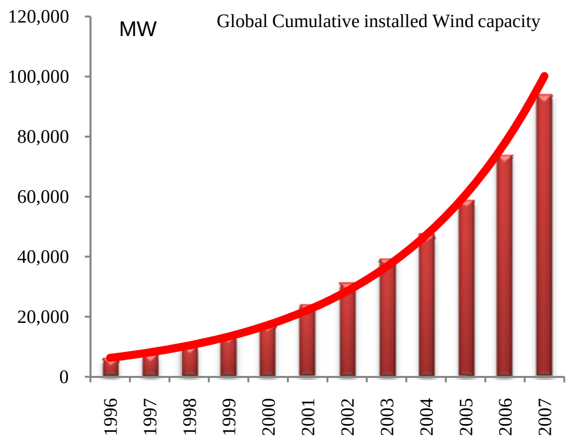

Figure 6 global wind power capacity

- **Intermittency issue and role of storage device to solve this issue**

The fact is that energy generation from renewable energy such as solar and wind is seldom constant over time and also electricity demand is never constant. Therefore, using an energy storage technology into renewable energy generating system is important. There are many different technologies available for storing energy. They come in all forms of energy such as mechanical, chemical, and thermal. Following energy storage devices have been explored, they are matured and leading the storage technologies: Battery storage; Pumped hydro storage; Thermal energy storage; Compressed air energy storage; Energy storage using flow batteries; Electrolyzer and Fuel cell; Flywheel energy storage; Superconducting magnetic energy storage; Super-capacitors. In terms of their applications, the energy storage technologies are divided in two categories:

- Low to medium power application to be used in isolated areas. These two categories are used where the energy could be stored as kinetic energy, chemical energy, compressed air, hydrogen, or in super-capacitors
- Large scale power applications where the energy could be stored as potential energy, thermal energy, chemical energy (flow batteries), or compressed air

Storage technologies are characterised by factors such as: Storage capacity; Available power; Depth of discharge or power transmission rate; Discharge time; Efficiency; Durability (cycling capacity); Self-discharge; Mass and volume densities of energy; Monitoring and control equipment; Operational constraints; Reliability; Environmental aspect, and etc.

6. Sustainable power system using solar, wind and a storage technology

A power system consisting of solar energy wind turbine together with a storage device can provide a sustainable system provided the system is properly engineered and the system components are correctly sized. Energy storage technologies provide opportunity for the generation side to meeting the level of power quality as well as reliability required by the demand side. Energy storage is especially important for decentralized power supply system by giving the more load-following capability, which is an important factor from generation side management.

- **Case study, a hybrid system**

A hybrid system is investigated, in which a load is supplied by a system consisting of solar energy, wind power and a storage device. The hybrid system of this study is shown in Figure 7. The main components of this system are solar PV array, wind turbine, and an energy storage unit. As a result of unpredictability of sun and wind, the output power from PV array and wind turbine is unpredictable. The storage unit is there to ensure that a reliable power is supplied to the load. The energy storage unit would be absorbing the excess generating capacity available during periods of low demand. Therefore, this excess energy is stored in the storage unit for later use. The stored energy can then be used to provide electricity during periods of high demand, helping to reduce power system loads during these times.

- **System simulation**

In order to analyse the operation as well as performance optimization of the system a simulation software tool has been used, taking into account the characteristics and efficiencies of all devices involved. As input data, the simulation tool uses both average wind speed data and sun radiation data, the peak sun hour (PSH), over a year and calculates the energy flux between the different segments. Depending on the size and efficiency of the devices selected (solar array, wind turbine), it is possible to predict the system's performance over the whole year. And also the overall system efficiency, the percentage of energy generated by solar array and wind turbine and capacity factor (CF) of each are determined.

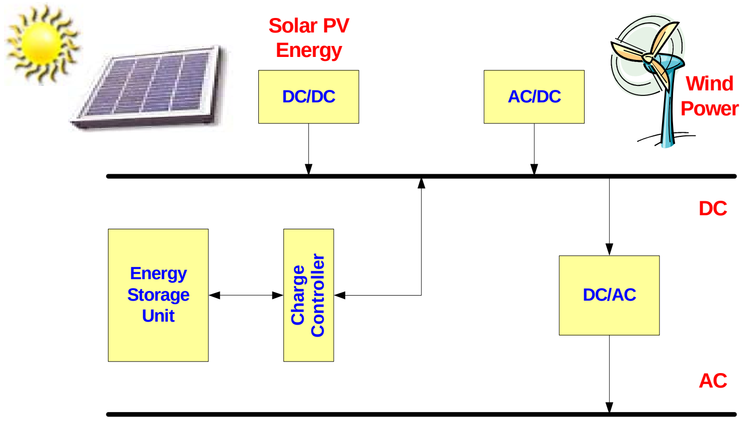

Figure 7 hybrid power system under investigation

The energy storage technology for this system can be of any type. In this study we used energy flow to and from storage unit in kWh and energy conversion efficiency, so type of storage device is not important. Table 1 shows information used for this simulation, while table 2 shows the simulation results. Graphical presentation of the simulation results are shown in Figure 8 to Figure 12.

# of WT	Rated WT	Eff. WT	Air Density	Radius, m	WS, m/s	Old H
1	330	0.45	1.05	10	6.25	10
New H	Roughness	De-Rating	PV-kW	Load/day	Efficiency	Storage
20	0.15	0.85	325	2650	0.85	300MWh

Table 1

Following equations were used to determine power production by wind turbine [12, 13]:

$$P(\mathrm{solar}) = \mathrm{size}\ (\mathrm{kW})\ .\ \mathrm{PSH}\ .\ \mathrm{De} - \mathrm{rating\ factor}$$

$$P(\mathrm{wind}) = 0.5\ \frac{6}{\pi}\ \rho\ A\ ((U^3)\mathrm{ave})/1000$$

Each is able to generate 50% of annual energy needed by the load.

- **Simulation Results**

Table 2 shows the simulation results. Graphical presentation of the simulation results are shown in Figure 8 to Figure 12.

Figure 8 shows power production by solar PV subsystem, Figure 9 shows power production by wind turbine, Figure 10 shows power production by solar PV and wind turbine, Figure 11 compares total power production with the demand, Figure 12 shows situation of storage device.

	Wind Speed (m/s)	Wind Power KW	Radiation	Solar Power	Power (Wind + Solar)	Load	Balance	Efficienc y	300000 MWh
Jan	6.30	36023	6.5	55664	91687	82150	9537	0.88	308393
Feb	5.30	20064	6.4	51272	71336	76850	-5514	1.14	302127
Mar	5.40	22685	5.5	47101	69786	82150	-12364	1.14	288077
Apr	5.90	28634	4.2	34808	63441	79500	-16059	1.14	269828
May	7.00	49414	3.2	27404	76818	82150	-5332	1.14	263770
Jun	8.30	79717	2.80	23205	102922	79500	23422	0.88	284381
July	7.50	60778	3.20	27404	88182	82150	6032	0.88	289689
Aug	6.70	43330	3.70	31686	75015	82150	-7135	1.14	281582
Sep	6.10	31645	4.60	38123	69768	79500	-9732	1.14	270522
Oct	6.70	43330	5.40	46244	89574	82150	7424	0.88	277055
Nov	6.30	34861	5.80	48068	82929	79500	3429	0.88	280072
Dec	6.90	47327	6.20	53095	100422	82150	18272	0.88	296152
Total		497808		484073	981880	969900	11980		
CF		17%		17%					

Table 2 simulation results

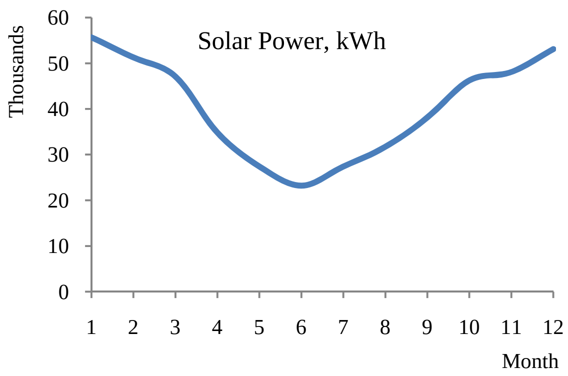

Figure 9 Power production PV

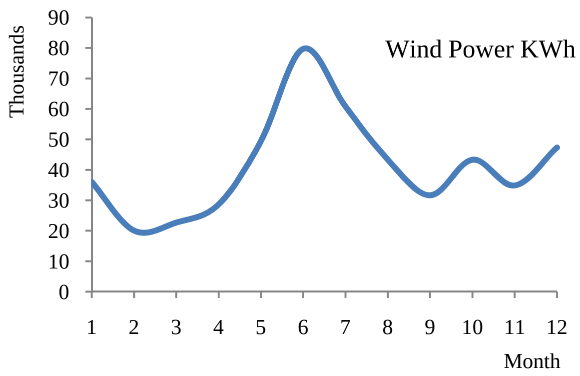

Figure 10 Power production, Wind

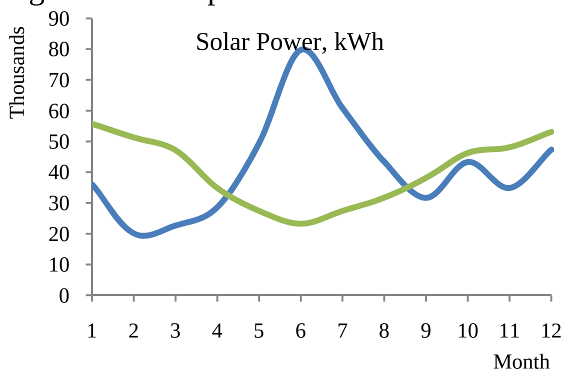

Figure 11 Total power production

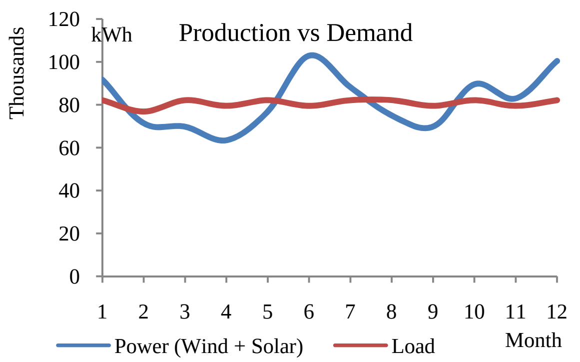

Figure 12 Power production vs demand

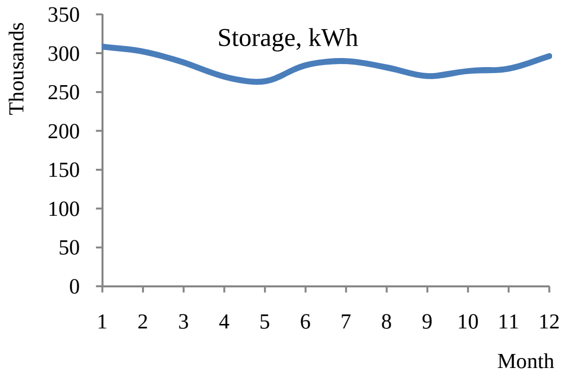

Figure 11 Situation of storage

7. Conclusions

The world is facing two major energy-related issues, short term and long term. These issues are i) not having enough and secure supplies of energy at affordable prices ii) environmental damages caused by consuming too much energy in an un-sustainable way. A significant amount of the current world energy comes from limited resources, when used can not be replaced, hence the energy production and consumption do not seem to be sustainable, and also carries the threat of severe and irreversible damages to the environment including climate change.

The price of energy is increasing and there are no evidences suggesting that this trend will reverse. To compensate this price increase we need to develop and use high energy efficient technologies and focusing on energy technologies using renewable sources with less energy conversion chains, such as solar and wind. World has the potential to expand its capacity of clean, renewable, and sustainable energy to off-set a significant amount of greenhouse gas emissions from conventional power use.

The renewable energy technologies in form of distributed generation can play a significant role in the mix of energy technologies to supply sustainable, reliable electric power.

8. References

[1] International Energy Outlook, Energy Information Association (EIA), Office of integrated Analysis and Forecasting, US Department of Energy, Washington DC, 20585, May 2007

[2] Key World Energy Statistics, International Energy Agency (IEA), Head of Communication and Information Office, 75739 Paris Cedex 15, France

[3] Dr Mark Diesendorf, “Australia’s Polluting Power”

[4] Oil & Gas Journal Online: http://www.ogj.com/index.cfm

[5] Organization of Petroleum Exporting Countries (OPEC), Annual Report 2008

[6] Keith Lovegrove, Presentation at Australian Academy of Science

[7] Paul Gipes, Wind Energy Comes of Age, John Wiley & Sons, 1995

[8] CSIRO: http://www.csiro.au/

[9] Zahedi, A., Australian Renewable Energy Progress, ELSEVIER, Renewable and Sustainable Energy Review, in press

[10] Global Wind Energy Council: http://www.gwec.net/
[11] Andrew Blakers, ANU, Notes on Solar Energy
[12] Zahedi, A "Low-emission and sustainable power supply for remote communities". Proceedings of the Inaugural Symposium on Electrical Energy Evolution in China and Australia In: Electrical Energy Evolution in China and Australia, 28-30 July 2008, Palm Cove, QLD, Australia
[13] Masters, G M "Renewable and Efficient Electric Power Systems", Wiley and Inter-science, 2004, chapter 6.
[14] Quirin Schiermeier, et al, "Electricity without Carbon", nature 454, 816-823 (2008

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